Refarming 1800MHz GSM Spectrum to LTE: The Effects on Coverage Based on Pathloss Estimation

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Abstract—**Pathloss estimation is largely frequency-dependent and its results indicate the coverage of any mobile network. The accuracy of these estimations is crucial for viable network designs and deployment. The rapid evolution of wireless communication technologies in recent decades has led to diversity in frequency bands. The need for spectrum harmonization for mobile broadband international roaming brought about the need for the refarming of the 1800MHz band from GSM to LTE. This paper investigates the impact of refarming of the 1800MHz frequency band from GSM to LTE in terms of network planning and deployment of LTE, using Okumura-Hata, COST 231 Hata and COST Walfisch-Ikegami pathloss estimation algorithms.**

Index Terms—**GSM, LTE, Pathloss, Refarming**

I. Introduction

The propagation of signals through space results in the diminishing of its power density as a function of distance. It also diminishes due to reflection, diffraction and scattering as the wave encounters objects in its path. These effects result in a phenomenon called Pathloss. Pathloss is therefore a very important factor in link budget analysis/design of any wireless system. Pathloss prediction/estimation algorithm results indicate the coverage of any mobile system; the accuracy of these predictions is crucial for viable network designs and deployment.

The rapid evolution of wireless communication technologies in recent decades [1] has led to rapid changes in frequency bands and other key elements. The Global System for Mobile Communication (GSM) family of technologies, grouped as 3GPP, is said to be the most successful, with the fastest evolution of mobile broadband delivery in the world [2]. Of these technologies, GSM itself is the oldest and most popular [3], with majority of its deployment around the world on the 900/1800MHz frequency bands. Other GSM bands include the 850/1900MHz bands [4]. However, the need for higher data rates due to the development of sophisticated services has driven the transition of wireless technologies to LTE. Spectrum harmonization for mobile broadband international roaming brought about the need for refarming of the 1800MHz band from GSM to LTE [2, 5]. As at February 2014, the Global mobile Suppliers Association (GSA) confirmed 1800MHz as the main band for LTE deployments worldwide [5].

GSM deployment began at 900MHz; but as wireless technologies evolved towards mobile broadband, the carrier frequency increased resulting in smaller cell sizes and increasing pathloss with distance [6]. The Okumura-Hata pathloss estimation model was the most common, but ITU recommended it due to its ease of use and reliability for early GSM cellular systems, characterized by macro cells. This research paper seeks to identify the impact of refarming of the 1800MHz frequency band from GSM to LTE, on network planning and LTE deployment.

II. Pathloss Estimation Algorithms/models

Pathloss estimation algorithms were developed to fit specific frequency bands, cluster type (country-side, sub-urban or urban), location (indoor or outdoor) and cell-size or range [7]. Pathloss prediction algorithms can be classified into three categories: theoretical, empirical and deterministic models. *Theoretical models* predict pathloss based on line-of-sight wave propagation through space (air). These models do not account for losses due to obstacles in the environment. The most common theoretical pathloss estimation model is the free space model. *Empirical models* predict pathloss using mathematical equations obtained from extensive field measurements. These models take into consideration factors such as frequency, antenna heights and distance between antennas. They demand more computational effort than the theoretical models. *Deterministic models* predict pathloss by considering the specific environment and the losses introduced by that particular environment. It computes net-pathloss using Maxwell’s equations obtained from actual measurements from the environment. Obviously, this method will produce more accurate results than the other models, but they are time-consuming and excessively computationally intense. Some pathloss estimation models are empirical but implement some deterministic-model characteristics. [8]–[10] provide details on several of these models.

The free space path loss is a key parameter in other pathloss estimation algorithms. This work focuses on the Okumura-Hata, COST 231 Hata and COST Walfisch-

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Ikegami models.

A. Free Space Pathloss Model

This pathloss indicates how much signal strength is lost as a signal propagates from transmitter to receiver through free space. Free space pathloss (L_O) in dB is given by:

$$L_O = 32.44 + 20\log f_c + 20\log d$$

Where f_c is the carrier frequency in MHz; and d is the distance between the base station (transmitter) and mobile station/user equipment (receiver) in km.

B. Okumura-Hata (Hata) Model

The Hata model [11] was formed based on pathloss measurements in Tokyo by Okumura [12]. This model is suitable for the 150-1500MHz range of frequencies, transmitter-receiver distances 1 – 20km, transmitter antenna height of 30 – 200m, receiver antenna height of 1 – 10m and macro cell environments. Hata's model returns the median pathloss in dB, given by:

$$L_P = 69.55 + 26.16\log f_c - 13.82\log h_B - a(h_M) + (44.9 - 6.55\log h_B)\log d\ (km)$$

Where,

$a(h_M)dB = 3.2(\log(11.75 \times h_M))^2 - 4.97$ for $f_c \geq 300MHz$

h_B is the transmitter antenna height in metres (m)

h_M is the receiver antenna height in metres (m)

$a(h_M)$ is the correction factor of the receiver height with respect to the coverage area size.

This model is not used for propagation in cellular systems with higher frequencies and smaller cell sizes. It also responds slowly as rapid changes are made to the terrain.

C. COST 231 Hata Model

Due to the simplicity and reliability of the Okumura-Hata model, the European Co-operative for Scientific and Technical research (COST) extended this model to cover frequencies up to 2GHz. This model also provides correction factors for pathloss estimation in different environments (rural, sub-urban and urban). The COST 231 Hata model pathloss in dB is given by [13, 14]:

$$L_P = 46.3 + 33.9\log f_c - 13.82\log h_B - a(h_M) + (44.9 - 6.55\log h_B)\log d + C_m$$

Where

$$C_m = \begin{cases} 0dB, & for\ medium\ sized\ /\ sub-urban\ areas \\ 3dB, & for\ urban\ areas \end{cases}$$

All other factors are valid as defined in the Hata model. However, the COST 231 Hata model requires the base station antenna height to be above rooftops adjacent to the base station.

D. COST Walfisch Ikegami Model

The COST 231 subgroup on propagation models proposed a combination of the Walfisch [15] and the Ikegami [16] models and named it COST Walfisch-Ikegami Model (COST-WI). This model, although more complex, allows for greater accuracy in pathloss estimation than the other models by including more parameters: height of buildings (h_{Roof}), width of roads (w), building separation (b) and road orientation with respect to the direct radio path (φ).

This model is valid for frequencies between 800MHz – 2GHz, transmitter antenna height of 4 – 50m, receiver antenna height of 1 – 3m and transmitter-receiver distances beginning from 20m to 5km.This model presents different equations for line-of-sight (LOS) and non-line-of-sight (NLOS) situations.

For LOS, COST-WI model uses a free space propagation equation which is different from the well-known free space pathloss model, on the condition $d \geq 20m$; it is given in dB by:

$$L_{LOS} = 42.6 + 20\log f_c + 26\log d$$

For NLOS, COST-WI model computes pathloss as a function of free space loss L_O, multi-screen diffraction loss L_{msd}, and rooftop-to-street diffraction and scatter loss L_{rts}.

$$L_{NLOS} = \begin{cases} L_O + L_{rts} + L_{msd}, & L_{rts} + L_{msd} > 0 \\ L_O, & L_{rts} + L_{msd} \leq 0 \end{cases}$$

Free space pathloss:

$$L_O = 32.44 + 20\log f_c + 20\log d$$

Rooftop-to-street diffraction and scatter loss:

$$L_{rts} = -16.9 - 10\log w(m) + 10\log f_c + 20\log \Delta h_{mobile} + L_{ori}$$

$$\Delta h_{mobile} = h_{roof} - h_{mobile}$$

$$L_{ori} = \begin{cases} -10 + 0.354\varphi, & 0 \leq \varphi < 35° \\ 2.5 + 0.075(\varphi - 35), & 35° \leq \varphi < 55° \\ 4.0 - 0.114(\varphi - 55), & 55° \leq \varphi \leq 90° \end{cases}$$

$\Delta h_{mobile}(m)$ is the height difference between the building on which the transmit antenna is located (h_{roof}) and the mobile antenna (h_{mobile}).

L_{ori} is the street orientation function, where φ is the angle of incidence with respect to the direction of the street.

Multi-screen diffraction loss:

$$L_{msd} = L_{bsh} + k_a + k_d\log d(km) + k_f\log f_c - 9\log b(m)$$

$$L_{bsh} = \begin{cases} -18\log(1 + \Delta h_{base}(m), & h_{base} > h_{roof} \\ 0, & h_{base} \leq h_{roof} \end{cases}$$

$$\Delta h_{base} = h_{base} - h_{roof}$$

$$k_a = \begin{cases} 54, & h_{base} > h_{roof} \\ 54 - 0.8\Delta h_{base}, & d \geq 0.5km, h_{base} \leq h_{roof} \\ 54 - 0.8\Delta h_{base}\dfrac{d(km)}{0.5}, & d < 0.5km, h_{base} \leq h_{roof} \end{cases}$$

$$k_d = \begin{cases} 18, & h_{base} > h_{roof} \\ 18 - 15\dfrac{\Delta h_{base}}{h_{roof}}, & h_{base} \leq h_{roof} \end{cases}$$

$$k_f = -4 + \begin{cases} 0.7(\frac{f_c}{925} - 1), & medium/suburban\ areas \\ 1.5(\frac{f_c}{925} - 1), & metropolitan\ areas \end{cases}$$

h_{base} is the base station antenna height.

k_d and k_f control the dependence of the multi-screen diffraction loss with respect to distance and the operating radio frequency.

L_{bsh} and k_a signify pathloss increase as a result of reduced base station antenna height.

The COST-WI model has been accepted by the ITU-R;

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however, it does not consider multipath propagation and the trustworthiness of the estimated pathloss decreases if the terrain is not flat.

III. Pathloss Simulation, Results and Discussion

MATLAB was used for this work. The Okumura-Hata and COST 231 Hata models have been chosen due to their simplicity and the capability to adapt to different terrains. Although Okumura-Hata model is not suitable for 1800MHz operating frequency, it is popularly used for 900MHz GSM networks. The COST-WI model has been chosen due to its higher accuracy by incorporating additional parameters to estimate pathloss. Ikeja, an area in Lagos Nigeria, was used as the reference urban environment for this work. Table 1 below presents an average of all required parameters used for pathloss estimation in this work.

TABLE I
Pathloss Estimation Parameters

Parameters	GSM	LTE
Frequency Band (MHz)	900/1800	1800
Environment	Urban	Urban
Radio Propagation	NLOS	NLOS
Transmitter Antenna Height (h_b)(m)	35	35
Receiver Antenna Height (h_m)(m)	1.5	1.5
Building Spacing (b)(m)	20	20
Distance (d) (km)	0.7:0.5:5	0.7:0.5:5
Building Height (h_{roof})(m)	15	15
Street Width (m)	10	10
Orientation Angle (φ)	90°	90°

As shown in Figure 1, 900MHz GSM presents a maximum pathloss of 152dB, by COST 231 Hata. Figure 2 shows 1800MHz GSM with a maximum pathloss of approximately 162dB. This shows that the 900MHz band has lower propagation losses, which is typical of low frequencies. At this frequency, wider coverage is also typical. The 1800MHz band is not as heavily used as the 900MHz band by GSM, it has more capacity and leads to greater frequency reuse suitable for urban centres when data traffic is high. Therefore refarming the 1800MHz band for LTE is a good choice. As shown in Figure 3, LTE deployment on the 1800MHz band presents a maximum pathloss of 162dB similar to that of 1800MHz GSM; therefore, LTE itself provides no boost to coverage. This means that 1800MHz LTE can be deployed utilizing the existing 1800MHz GSM sites.

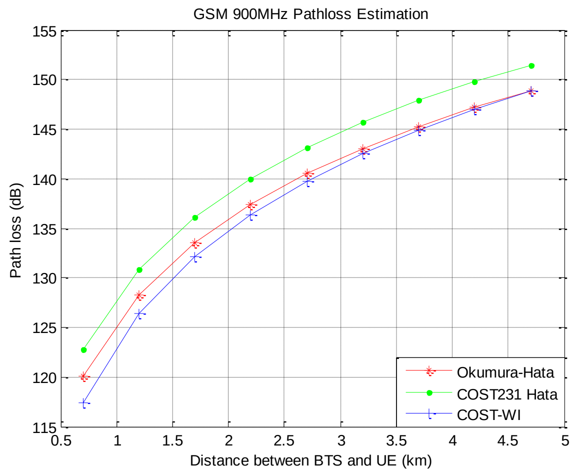

Fig. 1. GSM 900MHz Pathloss Estimation

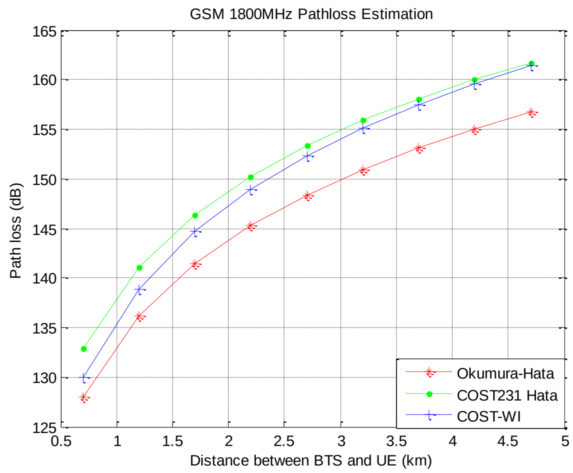

Fig. 2. GSM 1800MHz Pathloss Estimation

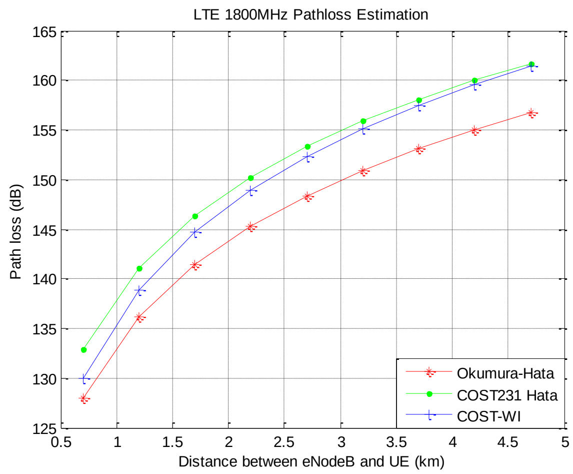

Fig. 3. LTE 1800MHz Pathloss Estimation

IV. Conclusion

In terms of coverage, the results show that network operators may deploy 1800MHz LTE using the existing 1800MHz GSM sites. The difference will be in how much more service can be offered by the service providers, how much more users may be accommodated within the same cell site as well as all other inherent benefits of LTE. LTE has clearly been proven to be an outstanding mobile broadband technology, comfortably delivering high data rates as demanded by users; notwithstanding, GSM still stands as the backbone of voice communication and international roaming. Leveraging the bandwidth flexibility of LTE by sharing the 1800MHz spectrum between GSM and LTE will provide a roadmap for eventual use of the 1800MHz band solely for LTE.

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